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Predicting Coastal Depositional Style: The Role of Accommodation/Sediment Supply and Basin Morphology within a Sequence Stratigraphic System on Selected Wells (Mid Miocene to Pliocene) in Coastal Swamp Depobelt, Niger Delta Basin, Nigeria

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Abstract

The depositional style of mid- Miocene to Pliocene sediments of selected wells in Niger Delta was studied to ascertain its dominating and influencing depositional system. The Ainsworth predictive model/trends were applied in determining the depositional system and styles, which takes into consideration the Basin morphology and accommodation/ sediment supply regime within a sequence stratigraphic system. The study suggests that depositional style of sequences 1,2,5 and 6 are fluvial- dominated, tide-influenced environment, which is marked by low wave effectiveness, high sediment supply/low accommodation and moderately embayed shoreline morphology, while sequences 3,4 and 7 are wave dominated, tide-influenced environment, which was noted with high wave effectiveness, low accommodation/high sediment supply and moderately embayed shoreline morphology. This study shows that the underlying basis morphology (moderately embayed) played a significant role in predicting the depositional style of the study area.

Keywords: sequence stratigraphy, accommodation/sediment supply, basin morphology, Depositional style and Niger Delta Basin.

INTRODUCTION

Many authors have researched on wave, fluvial and tidal dominance within a coastal depositional environment, which they have related to sea level changes. These authors have expressed the importance of changes in the underlying coastal morphology and rates of sedimentation and subsidence in predicting coastal depositional style (eg. Bhattacharya and Walker 1992; Boyd et. al. 1992, Cross .et al. 1993; Posamentier and Allen 1999; Bhattacharya and Willis 2001; Bhattacharya and Giosan 2003; Hoy and Ridgway 2003; Barton et. al. 2004; Gardner et.al.2004; Shuji et.al. 2006; Chiaghanam, 2007, Chiaghanam et.al, 2011). Some of these authors have tried to relate facies changes to rates of accommodation changes and sediment supply within a sequence stratigraphic perspective or framework, (Ainsworth et. al. 2005). Switches between wave dominance of deposystems during highstands to fluvial dominance during relative sea level fall in cretaceous Western interior basin of North American was done by Hampson et al. (1999). Ainsworth (2003) worked on the opposite relationship whereby deposystems changed from fluvial- dominance during highstands to wave-dominance during lowstand. Mellerre and Stell, (1995) recorded variation whereby switches from wave- dominance during highstands to tide- dominance during lowstand in the cretaceous Western interior Basin. The deposystem from tide-dominance/influence during transgression and highlands to wave- dominance during relative sea level falls in the Gallup sandstone of the Western interior basin was carried out by Cross et al. (1993).

Wave energy may also change as frictional damping of waves is strongly depth dependent, and is more rapidly attenuated on a shallow coastal zone with a gentle slope, with or without bed forms than a deep one with high gradient of slope. Such process changes transform coastal geomorphology and are known to have been common for shore-zone systems in the Holocene and pre-Holocene without realizing this potential environmental complexity, identification of bounding discontinuities and regional correlation can easily be incorrect, and paleogeographic reconstruction can be severely unrealistic Shuji et al. (2006). The study area (Niger Delta), which is regarded as a mixed- process type of delta are influenced fairly strongly by both tides and wind, hence the deltaic sediments are modified by both tidal and wave–related processes (Boggs, 2006). Galloway, (1975), Wright, (1985) and Bhattacharya and Walker (1992) all class the Niger delta as being an intermediate type delta exhibiting aspects of Fluvial-wave and tidal-influence. That is, it is considered to be a delta closed to being in an equilibrium state with approximately equal dominance of all three processes Ainsworth et.al 2005).

The objective of this paper is to establish bases that will help predict depositional style within a sequence stratigraphic perspective, with reference to basin morphological and accommodation/sediment supply changes and variations.

STUDY AREA

The three wells used in this study are located within three different fields in the offshore Niger Delta of Nigeria. See fig 1. The fields are pseudo named X,Y and Z, which are located within latitude : 5^0 E, 4^0N, longitude 5^0E, 2^0E;

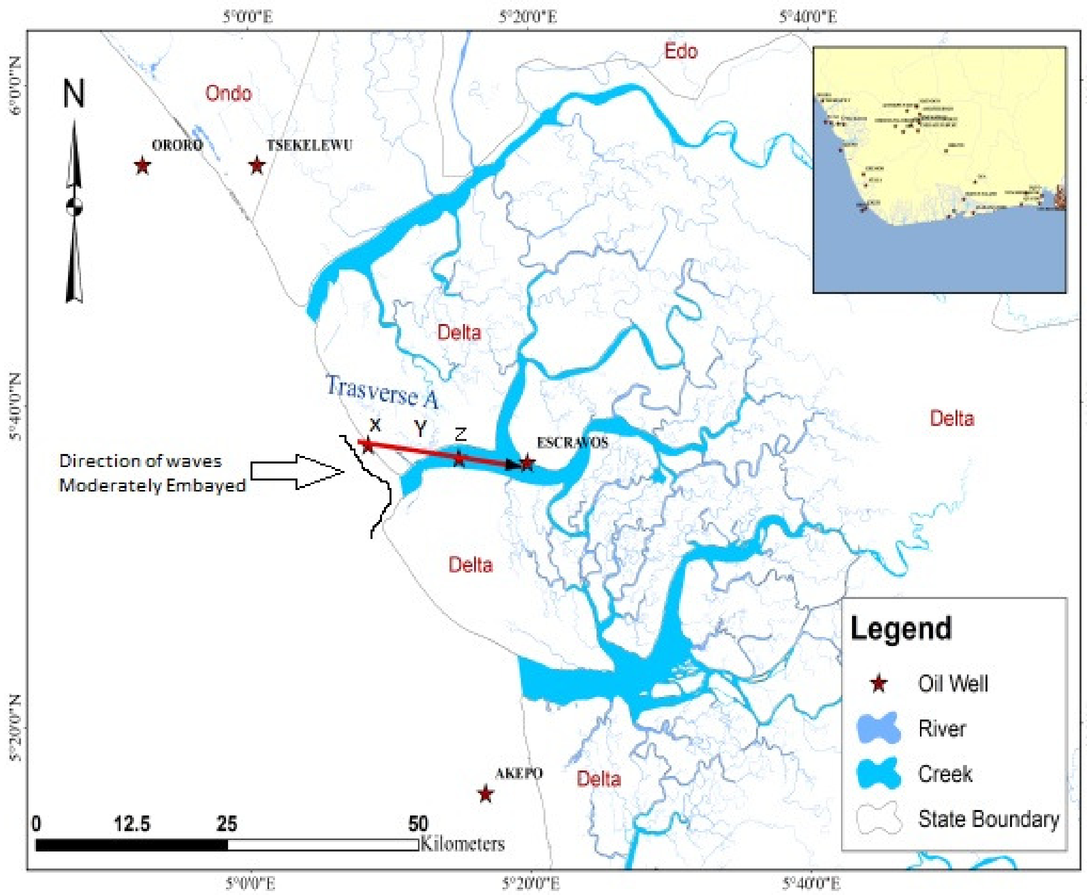

Figure 1: Map of the Study Area showing showing wave Approach direction (moderately embayed shoreline morphology)

GEOLOGIC SETTING

The Niger Delta, located in the gulf of Guinea, covers an area of over 70,000 square kilometers. Although the modern Niger Delta formed in the early tertiary deposits begin to accumulate in rift zones associated with the separation of the African and South American continents during the Mesozoic (Weber and Daukoru, 1975, Evamy et al, 1978, Doust and Omatsola, 1990 and Magbagbeola, 2004). Rifting was preceded by the intrusion of ring complexes in the central basement of Nigeria, these plutonic rocks may be related the upward-doming of the area prior to the rifting phase that followed. Syn-rift sediments accumulated during the Cretaceous to tertiary, with the oldest dated sediments of Albian Age. (Magbagbeola, 2004). Marine successions of syn-rift clastics and carbonates were deposited in a series of transgressive and regressive phases (Doust and Omatsola1989; Magbagbeola, 2004). The syn-rift phase ended with basin inversion in the Santonian (Late Cretaceous), possibly related to a reversal in pole of plates (Alpine Orogeny) movements. Subsidence resumed in Maastrictian as regressive proto-Niger delta (Anambra Delta) was initiated (Magbagbeola, 2004).

The proto-Delta continued to episodically prograde during the late cretaceous from sediments sourced largely from the north and east. The Niger, Benue and cross Rivers increasing supplied sediments from the late Miocene onward. The Delta has steadily prograded into the Gulf of Guinea in response to these evolving drainages, subsidence and eustatic sea level changes. The present delta shoreline is smoothly convex seaward, modified by wave and tidal processes. Niger Delta deposits are primarily a prograding package of offlapping strata, comprised of three distinct time-transgressive lithologic units, the Akata, Agbada and Benin Formations (fig 2). At the base of the package the Akata Formation, thick marine shale, is typically under-compacted, overpressed and mobile. The Agbada Formation overlies the Akata and comprises alternating paralic sands and marine shales. The Agbada contains most Niger Delta hydrocarbon accumulations; the interlayering of sand-shale strata offering excellent opportunities for reservoir and Top-seal formation. The uppermost Benin Formation is a thick continental sand deposit, (Magbagbeola, 2004).

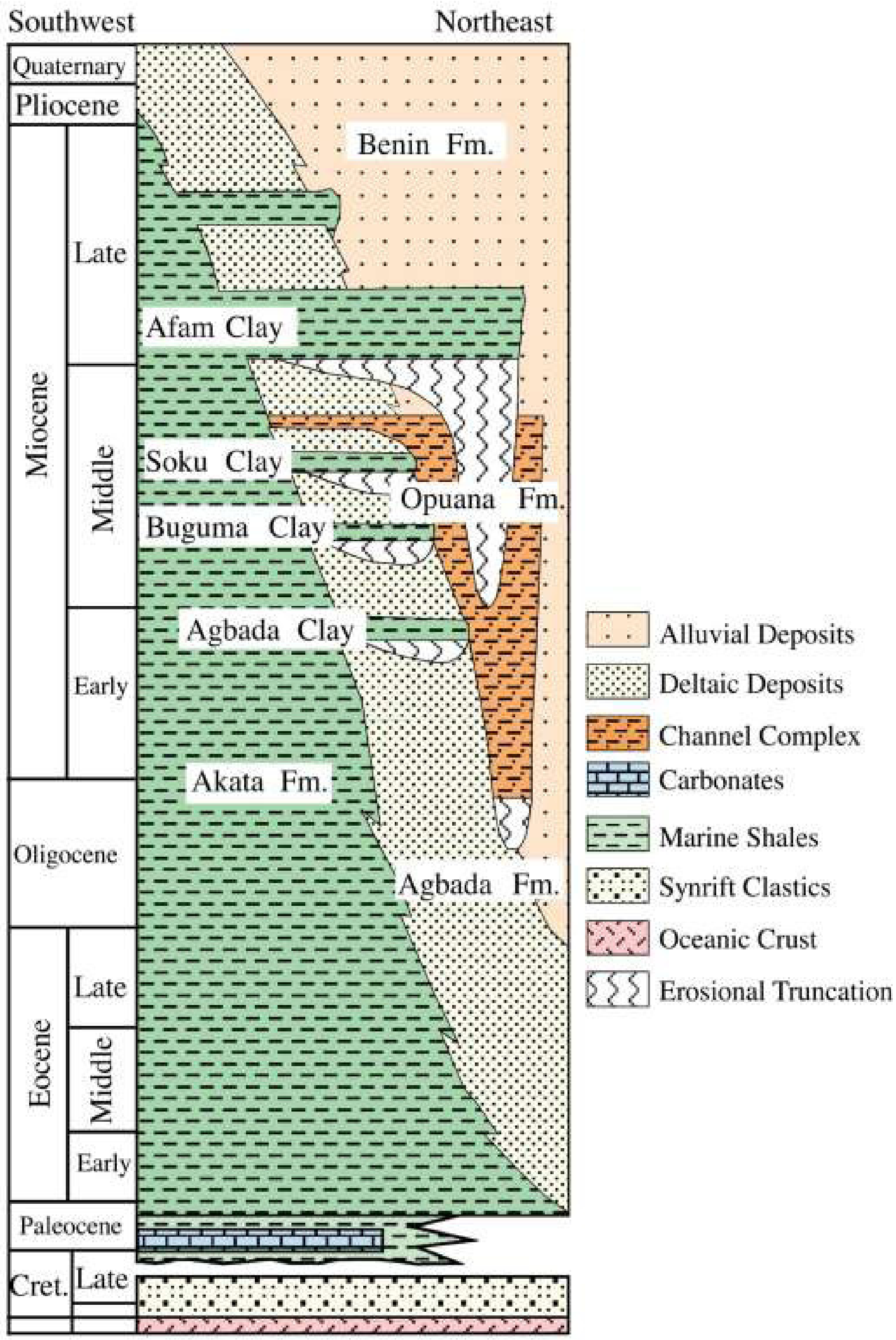

Figure 2: Stratigraphic column showing the three formations of the Niger Delta (Lawrence et.al 2002; Corridor et. al., 2005).

The delta is characterized by series of depositional cycles (referred to as depobelts), that strike northwest to southwest and run sub-parallel to the shoreline. Each depobelt comprises a sub-basin, bounded by a growth fault to the north, which creates anticlinal ridges, and a counter regional fault seaward. Each sub-basin contains a distinct depositional cycle with its own tripartite assemblage of marine, parallic and continental formations, which ranges in age from Eocene in the north to Pliocene in the southern offshore edge. Hydrocarbon accumulations in the Niger Delta are generally found in the Agbada Formation within the crestal portion of the sub-basins (Magbagbeola, 2004).

METHODOLOGY

The log suites were displayed of a consistent scale, chosen to entrance the log trend. The major trends on the log were marked (fig. 3). Intervals of progradations, retrogradations and aggradations from stacking patterns in parasequences/perasequence sets were determined and candidates for maximum flooding surfaces and sequence boundaries were marked from facies discontinuities and variations from Biofacies data. Absolute ages for these key stratigraphic surfaces were derived from curves of Hag et. al., 1987. Faunal abundance/diversity, paleowater depth and ditch cuttings were employed in determining depositional environment. Trends of parasequence thickening and thinning were interpreted, which suggests variations in the relative sea level rise/fall and influence of accommodation/sediment supply. The system tracts were interpreted using stacking patterns and positions of key stratigraphic surfaces. The general basin morphology (Embayment) within the study area were noted, while the predictive model of Ainsworth et al., 2005 was employed in predicting the depositional style of the study area (Fig. 4 and 5). The major prevailing process is termed the “dominant” depositional mechanisms and the second prevailing process is termed the influential depositional mechanisms, while the third prevailing process is termed affected. The three wells used in this study were interpreted for their depositional style from the perspective of depositional sequence according to Galloway, 1989.

INTERPRETATION

The changes in coastal depositional style have been attributed to changes in the balance between sediment supply and sediment storage capacity or accommodation (Cross 1988, Bhattcharya and Walker 1992; Boyd et al, 1992, Cross et al., 1993; Schlager 1993, Barton et al, 2004; (Gardner et al. 2004; Ainsworth et al, 2005, Chiaghanam et al, 2011). Based on Ainsworth et al 2005 model for predicting coastal depositional style (fig 4). If rates of sediment supply(s) outpaced rates of accommodation addition (A), the fluvial dominated deposition will occur (low A/S regime). IF the rate of accommodation development was greater than the rates of sediment supply, wave- dominated coastlines will predominate (high A/S regime). The model shows that the accommodation rate decreases during late highstand systems tract (late HST) (Fig 4b), thus allowing sedimentation rate (Fig 4 c) to outpace accommodation addition (low A/S regime) and resulting in fluvial-dominated coastline (fig.4d). The fluvial- dominated coastline will also prevail during falling stage systems tract (FST). Eventually, the rate of accommodation addition will outplace the rate of sediment supply during late lowstand systems tract, transgressive systems tract and early highstand systems tract (late LST, TST and early HST; fig. 4d) resulting in wave dominated coastline (Ainsworth, 2005).

The presence of tidal influence or dominated environment is attributed to paleogeography of the Basin (embayed nature) or of the study area, and if it persists, it shows that there was a potential mechanism for the generation of tidally- influenced or dominated deposits through complete relative sea level cycles. The increase in the magnitude of tidal power due to the geometry of the basin will increase the potential for preserving tidally-influenced deposits over sediments deposited by other processes (Fluvial and wave). If the embayed geometry of the basin persisted through rises and falls in relative seal level, then the tidal signature could also be expected to be preserved throughout the succession (Ainsworth et al., 2005). Hence Basin morphology is important in controlling the degree of tide on a depositional system (see fig.5). The more curved or embayed a shoreline is, the more likely it is to experience higher tidal ranges due to the amplification of the tidal wave as it moves into the irregular coastal morphology (Ainsworth et al., 2005)The three coastal morphologies shown in fig.5 (straight to lobate, moderately embayed and highly embayed) was applied in this work. Figure 5 was builds on the tripartite subdivision of deltaic coastlines (Galloway, 1975) into fluvial dominated, wave dominated and tide-dominated and convolves them with other external forcing factors on shoreline deposition identified by Coleman and Wright, (1975), Ainsworth et. al., (2005). The ternary diagrams in Fig 5 shows the relative influence of waves, river input and tides on coastlines under the prevailing external conditions of basin morphology used as a proxy for tidal influence, relative effectiveness of wave and fluvial energy and ratio of accommodation/sediment supply. The larger the area of a triangle covered by the depositional process (fluvial, wave or tidal), the greater the influence of that depositional mechanism under external conditions imposed. (Ainsworth et al, 2005).

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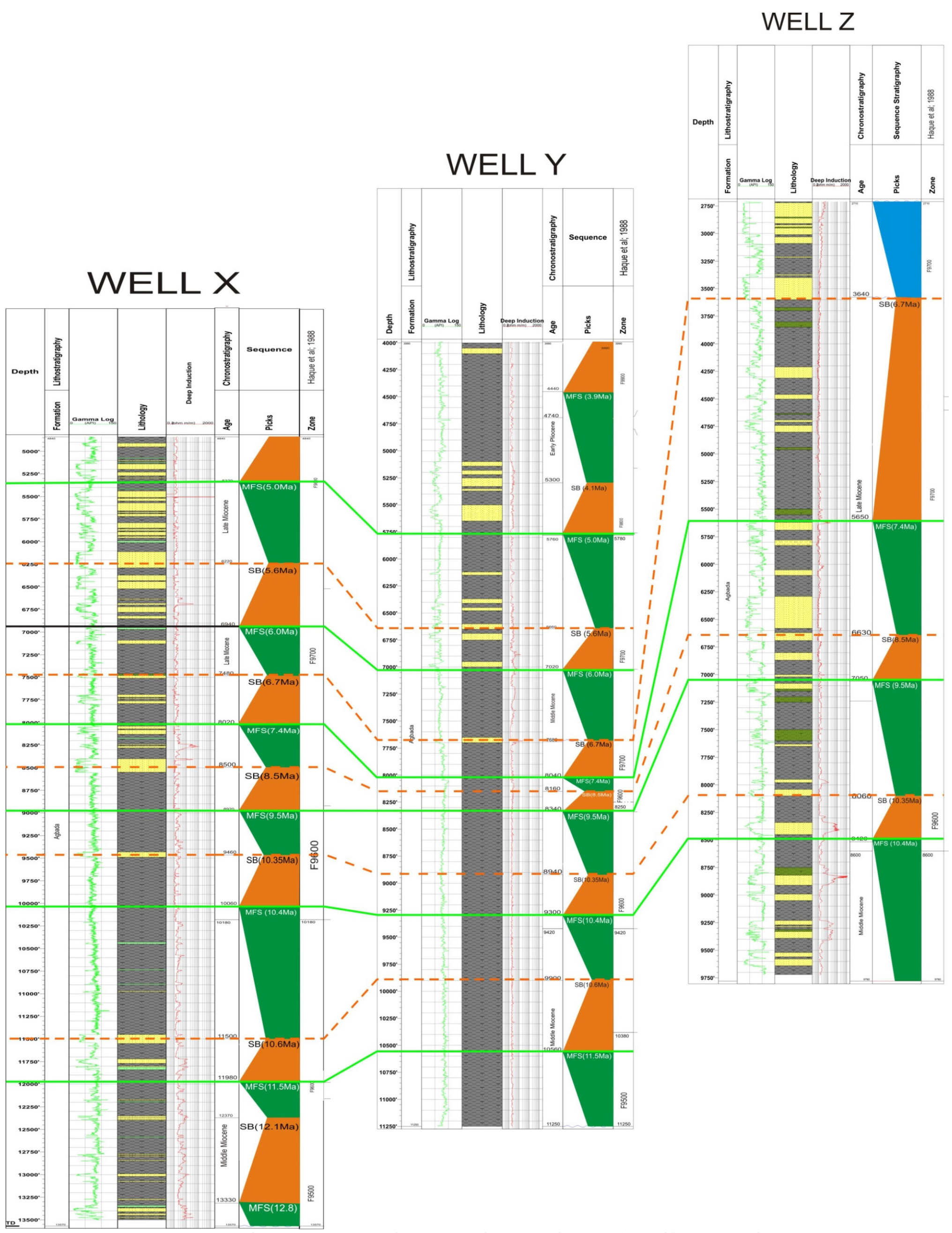

Fig 3. Chronostratigraphic Correlation Chart Of Well X,Y and Z

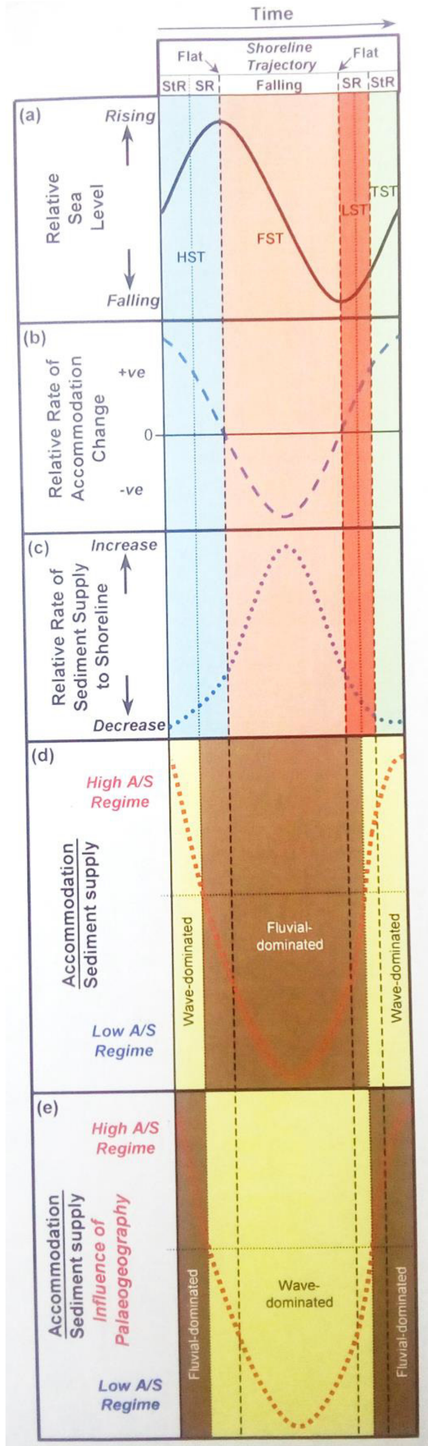

Fig. 4: Summary of changes in depositional style related to ratios of accommodation/sediment supply (A/S) (Ainsworth et.al 2005).

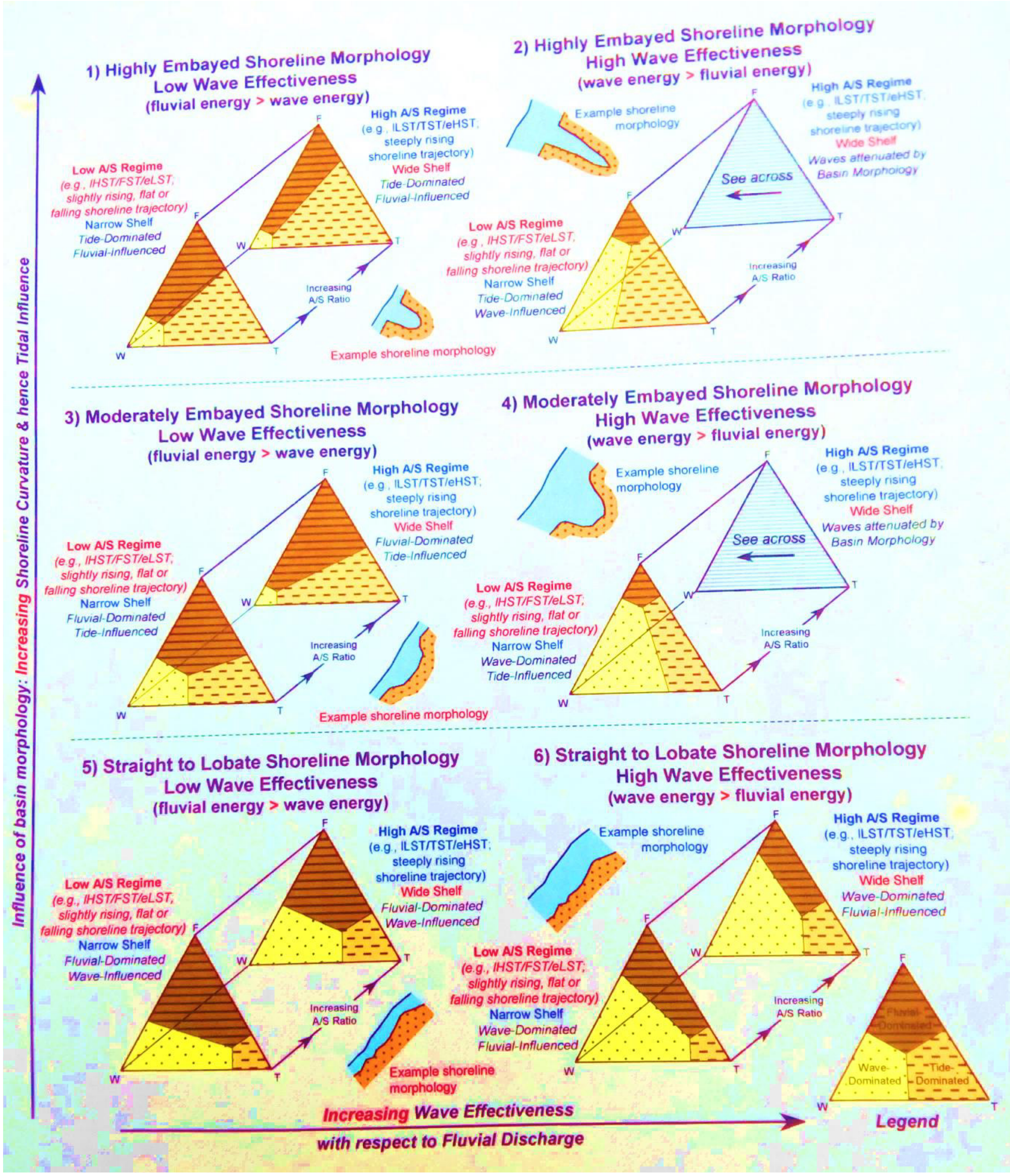

Fig. 5: Predictive model for dominant and subordinate depositional processes acting on clastic coastal depositional systems (Ainsworth et.al 2005)

The interpretation and prediction of the depositional style of the study area was based on sequence, which is the relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities (Mitchum, 1977). Seven sequences were identified as shown in Fig 3 and table 1. Sequences 1, 2, 5, 6 suggest an environment whose depositional style is fluvial- dominated, tide- influenced and wave affected. This prediction was based on

(a) That the environment recorded a low wave effectiveness which implies that the fluvial energy is greater than the wave energy,

(b) That the accommodation/ sediment supply regime recorded a high sediment supply and low accommodation. The sequence stratigraphic implication is late highstand systems tract, falling stage systems tract, early lowstand systems tract, slightly rising, flat or falling shoreline trajectory .A narrow shelf will be created by this attributes (Helland-Hansen and Martinsen, 1996).

(c) The basin morphology (embayed nature) paleogeography of the study area is regarded as being moderately embayed shoreline morphology, as shown in fig. 1. sequence 3, 4 and 7 suggests an environment whose depositional style is wave- dominated, Tide – influenced and fluvial affected. This prediction was based on
(a) That the environment recorded a high wave effectiveness which implies that wave energy generated within the sequence is greater than the fluvial energy.
(b) That the accommodation and sediment supply regime recorded a high sediment supply and low accommodation as seen in sequences 1,2,5 and 6. This implies late highstand systems tract, falling stage systems tract, early lowstand systems tract, slightly rising, flat or falling shoreline trajectory, and this will result in the development of narrow shelf (Heland-Hansen and Martinsen 1996).
(c) The basin morphology/paleography of the study area is regarded as being moderately embayed.

TABLE 1:.PREDICTIVE COASTAL DEPOSITIONAL STYLE SUMMARY TABLE FOR SELECTED WELLS IN COASTAL SWAMP DEPOBELT, NIGER DELTA BASIN, NIGERIA

WEST NAME	DEPTH RANGE	SEQUENCE	NIGER DELTA CHRONOSTRATIGRAPHYIC AGE	NIGER DELTA CYCLE SPDC	NIGER DELTA ROLLEN AND FORAMINIFERU ZONATION			NIGER-DELTA DEPOBELT PENETRATED	SYSTEM TRACT WELL X	SYSTEM TTRACT WELLY	SYSTEM TRACT WELL Z	AGE OF MFS & SB WELL X	AGE OF MFS & SB WELL Y	AGE OF MFS & SB WELL Z	SHORELINE MORPHOLOGY	WAVE EFFECTIVENESS	ACCOMMODATION & SEDIMENT SUPPLY REGIME	PREDICTED DEPOSITIONAL STYLE
X Y	6250 to 4900 ft 6650 to 5350ft	7	Late Miocene	10	P 870 P 860 P 850		F 9800 F 9700	COASTAL SWAMP TO OFFSHORE	6250 to 5350 (TST) 5350 to 4900 (HST)	6650 to 5750 (TST) 5750 to 5300 (HST)		SB 4.1MY MFS 5.0 M Bolivina -46	SB 4.1My MFS 5.0 MY Bolivina -46		Moderatel y Embayed shoreline morpholog y	High wave effectiveness (wave energy> fluvial energy)	Low accommodatio n High sediment supply	Wave dominate d Tide influence d Fluvial affected.
X Y	7500 to 6250 ft 7700 to 6650 ft	6			P 840 P 830				7480 to 6840 (TST 6840 to 6250 (HST)	7700 to 7050 (TST) 7050 to 6650 (HST)		SB 5.6MY MFS 6.0 MY Haplophragmoid es-24	SB 5.6My MFS 6.0 MY Haplophragmoid es-24		Moderatel y Embayed shoreline morpholog y	Low wave effectiveness (fluvial Energy> wave energy).	High sediment supply Low accommodatio n	Fluvial-dominate d Tide-influence d Wave-affected.
X Y Z	8500 to 7500 ft 8150 to 7700 ft 6600 to 3600 ft	5			P 820		F 9600		8500 to 8020 (TST) 8020 to 7480 (HST)	8150 to 8040 (TST) 8040 to 7710(HS T)	6630 to 5650 (TST) 5650to 3650 (HST)	SB 6.7mY MFS 7.4 MY un-named	SB 6.7 my MFS 7.4 MY Un-named	SB 6.7 my MFS 7.4MY Un nsmed	Moderatel y embayed Shoreline morpholog y	Low wave effectiveness (Fluvial energy > wave energy)	High sediment supply Low accommodatio n	Fluvial-dominate d Tide-influence d Wave-affected
X Y Z	9495 to 8500ft 8950 to 8150 ft 8100 to 6600 ft	4			P 780	P 788			9450 to 9000 (TST) 9000 to 8500 (HSS)	8940 to 8340 (TST) 8340 to 8150 (HST)	8150 to 7050 (TST) 7050 to 6630 (HST)	SB 8.5MY MFS 9.5My U vigerina -8	SB8.9 my MFS 9.5my U vigerina -8	SB 8.5MY MFS 9.5my Uvigerin a-8	Moderatel y embayed Shore line morpholog y	High wave effectiveness (WAVEl energy > FLUVIAL energy)	Low accommodatio ns High sediment supply	Wave dominate d Tide influence d Fluvial affected
X Y Z	1150 to 9495ft 9900 to 8950 ft Base to 8100 ft	3	Middle Miocene	9	P 770	P 784			11500 to 10050 (TST) 10050 to 9450 (HST)	9900 to 9300 (TST) 9300 to 8940 (HST)	9750 to 8500 (TST) 8500 to 8150 (HST)	SB 10.35my MFS 10.4my Nonian -4	SB 10.4my Nonion -4	SB 10.35my MFS 10.4my Nonion - 4	Moderatel y embayed Shore line morpholog y	LOW Wave effectiveness(FLUVIA Le energy > WAVEl energyy)	Low accommodatio n High sediment supply	Wave dominate d Tide influence d Fluvial affected
X Y	1228 0 to 1500ft Base to 9900 ft	2			P 740	P 750	F 9500		12280 to 11980 (TST) 11980 to 11500 (HST)	11250 to 10500 (TST) 10500 to 9900 (HST)		SB 10.6my MFS 11.5 My Dodo Shale	SB 10.6my MFS 11.5my Dodo Shale		Moderatel y embayed Shore line morpholog y	Low Wave effectiveness(fluvial energy > wave energy)	High sediment supply Low accommodatio ns	Fluvial-dominate d Tide – influence d Wave-affected
X	Base to 1228 0	1		8		P730			13500 to 13330 (TST) 13330 to 12280 (HST)			SB 12.1my MFS 12.8my Cassidulina -7			Moderatel y embayed Shore line morpholog y	Low Wave effectiveness Wave energy > Fluvial energy	High sediment supply Low accommodatio n	Fluvial-dominate d Tide – influence d Wave-affected

Conclusion

The research indicates that ratios of accommodation/sediments and basin morphology have significant role in determining depositional style. The Ainsworth predictive model/trends shows the influence of wave, river input and tides on coastline under prevailing external conditions of basin morphology used as a proxy for tidal influence relative effectiveness of wave and fluvial energy and ratio of accommodation space/sediment supply. As a general role, the more curved or embayed a shoreline, the more likely it is to experience higher tidal ranges due to the amplification of the tidal wave as it moves into the irregular coastal morphology (Ainsworth et al

2005, Chiaghanam et al., 2011).It is assumed that the depositional products of the "dominan" process will have the highest preservation potential and those of the "influential" process will have the second highest preservative potential (Ainsworth et al., 2005). This worth have further supported research done by past workers, who suggested that Niger Delta is an intermediate type delta exhibiting aspects of fluvial wave- and tide influences (Equilibrium state) or an intermediate phase between extreme low or extreme high accommodation space and sediment supply regime.

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